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DRILLING WELLS IN OKLAHOMA BY THE MUD-LADEN FLUID METHOD

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BY

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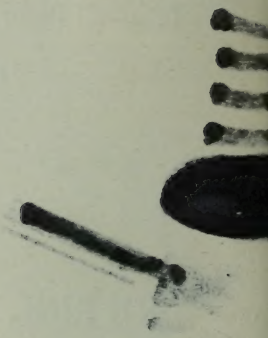

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DRILLING WELLS IN OKLAHOMA BY THE MUD-LADEN FLUID METHOD.

By A. G. Heggem and J. A. Pollard.

INTRODUCTION.

The waste of natural gas in Oklahoma has been enormous, and unless methods of preventing this waste are adopted the wealth of that State will be decreased, not only by the intrinsic value of the gas wasted, but by loss of income obtained from those communities and industries whose prosperity and life depend on the existence and utilization of this ideal fuel. Furthermore, the rapid removal of gas from oil-bearing beds tends to decrease the total yield of oil. The saving of the gas is important to the oil producer also, for the use of gas to generate power makes it possible to operate profitably an oil lease that otherwise may have to be abandoned, and this, too, at a time when the revenue, though small, is steady. At many wells in the older oil fields the natural gas has been wasted, and crude oil, or more generally gasoline, has been used to generate the power to pump the oil, thus increasing the cost of production. The maximum yield of oil can be obtained only where a fuel as cheap and efficient as natural gas is available.

During the winter of 1912–13 the development of the Cushing field in Oklahoma became very active, and many wells were drilled to the deeper sands which contained large volumes of natural gas. The enormous waste of the gas encountered during the drilling for oil called forth protests from various sources, and appeal was made to the President of the United States and to the Secretary of the Interior in behalf of the landowner and of the public welfare.

The facts were wanted regarding the amount of the waste and the technical conditions that were responsible for practices causing it.

An investigation was ordered and conducted under the direct supervision of J. A. Holmes, Director of the Bureau of Mines, who in the latter part of March sent the writers to Oklahoma to study well-drilling methods with reference to the waste of gas from wells on Indian lands and to suggest means of preventing the waste of natural gas on such lands.

This paper records the experience of the investigators in introducing a method of drilling that is not attended by the waste of gas that often accompanies the usual method of drilling with cable tools.[a]

DESCRIPTION OF THE CUSHING FIELD.

The Cushing field is in the west side of Creek County, in Tps. 17 and 18 N., R. 7 E., and is 12 miles east of the town of Cushing, from which it takes its name.

The field, in the summer of 1913, was about 7 miles long and 3 miles wide, and was producing oil from two distinct sands. Gas had been encountered in four or more distinct sands.

The principal producing sands are as follows:

An unnamed sand is found at a depth of 600 feet in the northern part of the field that yields 40,000,000 cubic feet of gas per 24 hours, with a rock pressure of 200 pounds from wells as usually finished.

The Layton sand at 1,450 feet was originally the principal oil sand; it yielded some gas with the oil, and is now partly exhausted.

The Jones sand at 1,700 feet is producing mainly gas, the volume per well being 6,000,000 to 8,000,000 cubic feet per 24 hours.

The Cleveland sand at 1,900 feet has shown both oil and gas, but is not considered capable of a large production.

The Wheeler sand at 2,200 feet is now the main producing sand both of oil and gas; the volume of gas per well is 20,000,000 to 40,000,000 cubic feet per 24 hours.

The Bartlesville sand at 2,800 feet, and the Mississippi sand at 3,200 feet, believed to be present, have not been explored.

During March, 1913, there were in the Cushing field 44 wells completed, of which 3 were gas wells; at the same time there were 118 wells being drilled and 58 additional rigs were up. In May, 1913, there were 176 wells being drilled and 67 rigs up.

FORM OF DRILLING CONTRACT.

Practically all of the wells are drilled by contract. These drilling contracts are usually made verbally and in accordance with prevailing custom. Considerable latitude is permitted because of variable conditions. The following is a typical form of drilling contract:

This agreement, made this.....day of.....A. D. 19..
between.....of.....
part....of the first part, and.....Company, a..... Corporation, party of the second part.

Witnesseth: That said part.... of the first part hath covenanted and agreed with said party of the second part, its successors and assigns, that said part.... of the first

[a] Pollard, J. A., and Heggem, A. G., Mud-laden fluid applied to well drilling: Technical Paper 66, Bureau of Mines, 1914, 21 pp.

part will drill for said party of the second part a certain well for the purpose of obtaining petroleum oil or natural gas, to be known as Well No. .... on the farm of .....
.....
.....Section.....Town.....Range.....
.....Township.....County.....

The material, machinery, and appliances necessary for drilling and completing said well shall be furnished, and the work of drilling the same shall be done in the manner hereinafter specified, viz:

A complete carpenter's rig of good quality (including wooden conductor), to be furnished by the part.... of the ..... part (and all repairs on same while the well is being drilled, shall be made by and at the expense of said part.... of the ..... part).

All casing to be furnished by part.... of the ..... part.

Boiler, engine, belt, bull rope, steam and water pipe and connections to be furnished at the well by part.... of the ..... part.

The expense of fitting up and connecting same to be borne by part.... of the ..... part.

Fuel to be furnished at expense of the part.... of the ..... part.

Water to be furnished at the expense of the part.... of the ..... part.

Oil saver and steel measuring line at expense of the part.... of the ..... part.

All machinery, material, and appliances furnished by said party of the second part shall, at the completion or abandonment of said well, be returned to said party of the second part in as good condition as when received by said part.... of the first part, ordinary wear and the action of the elements alone excepted.

The said part.... of the first part further agrees to pay all expenses and furnish everything necessary to drill and complete said well except the articles and appliances herein specifically mentioned to be furnished by the party of the second part.

The said well, unless sooner abandoned by direction of the party of the second part, is to be drilled.....
.....
the consideration for which shall be.....per foot.

All fresh water shall be cased off with casing of a diameter of not less than..... inches, and all salt water cased off with casing of a diameter of not less than ..... inches.

The diameter of the well when completed shall not be less than ..... inches.

When the said well approaches the oil or gas bearing sand, the part.... of the first part shall notify the party of the second part, or its agent in charge of the farm or lease, and thereupon any further drilling and casing into or through the sand, shall be as requested by the said party of the second part, or its agent in charge of the farm or lease, but the work in connection therewith shall be done by and under the direction and at the risk of the part.... of the first part.

If oil or gas is found in sufficient quantities to endanger the rig, material, or equipment, part.... of the first part shall assume the risk thereof and remove at ..... own expense the fires and boilers to a safe distance from the well. All pipe and fittings made necessary by such removal shall be furnished by said part.... of the ..... part.

When completed, unless prevented by too great a volume of gas or oil, the well shall be thoroughly "bailed" and "sand pumped" by said part.... of the first part until all drillings and sediment are removed therefrom and the well thoroughly cleaned.

The part.... of the first part shall carefully examine the rig, all machinery, casing, and other appliances to be furnished for said well by the party of the second part, and if any defect be found therein sufficient to make the use of such rig, machinery,

casing, or other appliances unsafe shall immediately notify the party of the second part of such defect or defects, and the party of the second part shall at once replace the article so found defective with a good and safe one; but if the part.... of the first part shall not make such examination, or shall not report any defects in said rig, machinery, casing, or other appliance ..... shall be deemed to have assumed all risks and all responsibility for any mishap which may occur in the drilling of said well by reason of a failure in such rig, machinery, casing, or other appliance.

No part of the contract price above mentioned shall in any event be paid until said well shall be completed to the depth above required, and delivered to the party of the second part, in thorough good order, free and clear of all obstructions .....

The part.... of the first part agrees.. to begin the drilling of the said well within .... days from ..... and prosecute the work actively and continuously (Sunday excepted) to completion .....

It is further agreed, that time shall be of the essence of this contract, and that in case the part.... of the first part shall neglect or discontinue the work of drilling said well for the space of ..... days, such neglect or discontinuance shall of itself be a forfeiture of all rights and claims of the part.... of the first part under this agreement without any notice or demand by the party of the second part. The party of the second part shall have the right at any time after such forfeiture to take possession of said well.., discontinue the drilling thereof, and at its pleasure dismantle or abandon the same without liability to the part.... of the first part for any portion of the contract price above mentioned. The party of the second part shall also have the right at any time after such forfeiture as above mentioned if it so elects to take possession of said well and all the ropes, tools, and appliances thereat of the part.... of the first part and drill said well to completion. In case it shall succeed in completing said well, the cost of such completion without any allowance to said part.... of the first part for the use of said ropes, tools, and appliances shall be deducted from the contract price above mentioned, and the balance, if any, paid to the part.... of the first part; but if said party of the second part should not succeed in completing said well, it shall not be liable to the part.... of the first part in any sum whatever and shall return said tools, ropes, and appliances to the part.... of the first part in as good order as when received, natural wear and tear and accidental loss or breakage excepted.....

After the drilling of the well, should the party of the second part desire to torpedo and clean out after the torpedo, the first party agrees to do the work at .... dollars per day of .... hours.

All risk and damage to tools, derrick, or equipment shall be assumed by the part.... of the first part at all times until all work to be done under this contract is fully and finally completed and the well is accepted as completed by the party of the second part.

In witness whereof, the part.... of the first part ha.... hereunto set ..... hand and seal and the party of the second part has caused these presents to be signed by its ..... the first above written.

Witnesses:

.....(Seal.) .....(Seal.) .....(Seal.)

Drilling contractors are apt to be inclined to disregard the interests of the owner and the public welfare and to devote their energies to "making hole;" that is, to drilling to a maximum depth in the shortest time and with the least cost. Suspension of work to test the tightness of casing or to case off water or gas is not viewed favorably by the contractor, who receives, during such suspension of drilling, a daily sum that usually is little more than his expenses.

DRILLING WELLS BY THE "DRY-HOLE" METHOD.

The method of drilling employed in the Cushing field is similar to that employed in all eastern and northern oil fields and is called the "dry-hole" method of cable-tool drilling, as the hole is drilled with all water cased out. Only enough water is used to keep the drillings slushy, so that the drill bit can strike the rock at the bottom and do its work and the bailer can pick up the drillings and clean the hole.

The "string of tools" regularly used in drilling with a cable rig consists of a bit, auger stem, jars, and a rope socket.

A hemp drilling cable is used in starting a well, and the best quality of hawser-laid Manila hemp cable is obtained wherever possible. When the well has reached such a depth that the long drilling line, by its resilience, serves to reduce the shock to the walking beam, a steel drilling cable, having 6 strands of 19 wires each, is substituted for the Manila cable.

The drill hole is started with a large bit, and a wooden conductor or a surface string of metal pipe is set through the top soil to bed rock. A smaller bit is then used and drilling proceeds until, owing to the caving of the wall of the hole or an excessive inflow of water, it becomes necessary to case the hole to prevent its caving or to keep out water. If possible the hole is continued through the caving or water-bearing bed to the first bed hard and strong enough to support the full weight of the casing, and a string of casing is inserted from the surface to this bed.

The average time required to drill a well to the Wheeler sand in the Cushing pool is about 50 days. The hole is usually started 18 inches in diameter and 16-inch casing is set to a depth of 20 to 60 feet. From this point the hole is carried down with a diameter of 16 inches to a depth of 500 to 600 feet, when 12½-inch casing is set. It is necessary to set 10-inch casing at about 800 feet and 8-inch casing at a depth of about 1,200 feet. From 1,200 feet it is usually possible to drill open hole to the top of the Wheeler sand at about 2,200 feet, when 6⅝-inch casing is placed.

When possible the hole is drilled into the oil sand and finished with the 6⅝-inch casing as the flow string. However, where gas is encountered it frequently becomes necessary to insert 5$\frac{3}{16}$-inch casing and to finish the hole 5 inches in diameter.

DRILLING THROUGH CAVING ROCK.

It sometimes happens that a stratum caves so badly that the hole fills as fast as made and the drill can not penetrate to hard rock below. In this event the string of casing is inserted and supported at the top of the well, and as the hole is deepened length after length

of casing is added, the whole string being lowered and allowed to follow the drill, until a hard bed that arrests its progress is encountered.

If a caving stratum is struck below the hard bed in which the casing is set, it is customary to introduce another string of casing. As each string of casing must pass through the preceding string, and the drill bit must be smaller than the innermost string of casing, the size of the bore hole is reduced with each string of casing inserted until it becomes so small that no further casing is possible and the hole must be abandoned.

To avoid reducing the size of casing too soon, it is customary to use an underreamer, which is a form of expanding bit that can drill a hole larger than the casing through which it passes. The casing is raised 5 or 6 feet from its seat and the underreamer is put on a string of tools in the same manner as an ordinary solid bit. The hole through the hard formation on which the casing was seated is then reamed out enough to allow the casing to pass. The same string of casing may thus be used in drilling through two or more caving strata.

By the use of an underreamer it is often possible to avoid using one or more extra strings of casing and many wells have been saved from abandonment. The limit of this method of sinking a casing is reached when the friction of the cavings against the casing becomes so great that the casing is "frozen" and can not be made to go farther, even by driving. The hole must then be reduced and a string of smaller casing inserted.

When the well is completed, the intermediate strings of casing are withdrawn, leaving the surface string and the inner or flow string. At some wells the casing next outside of the flow string is also left in as a water string to protect the producing sands from water in overlying strata.

SEATING THE CASING.

As casing is used to shut out water as well as to prevent caving, it must be properly seated in order to make a water-tight joint.

The common way of seating casing is to screw a thread protector on the lower end and to rest this protector on a shoulder prepared in the rock. Sometimes a few feet of sand pumpings are left in the hole before the casing is inserted in order to make the joint tighter. However, this practice does not insure good results and wells may be ruined eventually by faulty seating of the casing.

A better practice, which can be used to advantage, is to provide the casing with a long shoe, about 4 or 5 feet in length, and of the same outside diameter as the casing couplings. The hole in the formation in which it is desired to seat the casing should be drilled with a

smaller bit and with a short stroke or "drilled off tight," making a smooth, tapered hole. In such a hole the casing shoe will fit snugly with a long bearing contact, and yet can be withdrawn when desired.

All casing should be tested after seating for absolute tightness before the hole is drilled deeper, and if found to leak should be withdrawn and reseated.

USE OF PACKERS.

Packers are used in many wells to shut out water or gas, and when properly applied serve their purpose well. A judicious use of packers may occasionally save the use of an extra string of casing. These packers are made in various types to suit special needs. The most common type consists of two telescoping steel cylinders inclosed in a rubber cylinder varied in thickness and length to meet different conditions. The component parts are so arranged that the weight of the casing when set is carried by the rubber, which expands outwardly and is intended to tightly fill all irregularities of the wall of the well, preventing the passage of water or gas.

Whenever one of these packers is removed after being seated it must be repaired or a new packer substituted before a tight joint can again be made.

When a string of casing has been set it is usual to cut the last or top joint on a level with the derrick floor and bell out the top with a sledge hammer to present a smooth surface to the drilling line. It is impossible to put screw fittings on the top of a well with casing thus battered, and usually the well is allowed to go "wild" if gas is unexpectedly encountered. The short joint of battered casing must be removed while the well is "wild," and a new joint, cut and threaded to proper length, must be put on, after which the usual screw fittings for closing in a well may be applied.

CONNECTING THE WELL TO THE FLOW LINE.

The usual method of connecting up an oil well (fig. 1) is to place a casing-head tee on the top of the inner string of casing, connect a flow line to the side outlet, and extend the line to a flow tank without providing means of controlling the flow or of shutting it off. The top opening of the tee is closed by a casing top, which seats flat within the tee and is held in position by four sharp-pointed set screws arranged radially through the top of the tee. The hole in the casing top, originally provided for the tubing to pass through, is closed by a wooden plug driven in from the underside. The device is useless under high pressure and is dangerous under moderate pressures.

WASTE OF GAS IN DRILLING AND CASING WELLS BY THE DRY-HOLE METHOD

The greatest and most evident waste of natural gas occurs when a well is allowed to go "wild" after being drilled into a gas-bearing stratum. Other wastes of perhaps as great importance occur in drilling by the usual methods. Gas is often allowed to escape freely while a well is being drilled through a gas-bearing sand in the search for oil(fig. 2). In some wells an attempt is made to save the gas by shutting it in with a string of casing having a packer at the bottom and a stuffing-box casing head, known as a bradenhead, at the top. Between the packer and the casing head there is usually a large

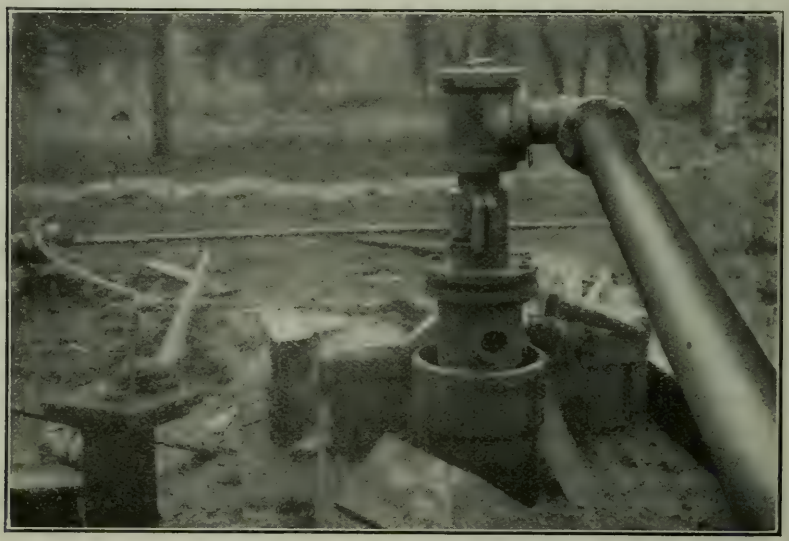

FIGURE 1.—Oil well connected to flow line, showing the tee casing-head and flow line connected to side outlet.

amount of open hole; that is, a hole in which the gas is confined in direct contact with the strata penetrated, and the strata may be porous. Much of the gas enters the more permeable strata, sometimes forcing its way to great distances and is lost, so that when the well is opened at a later day the available supply of gas has decreased to such an extent that it is of practically no value to the owner. This subterranean movement of natural gas sometimes leads to the rejuvenation of exhausted gas sands, which has been observed in some of the older fields, and in other instances has constituted a formidable danger by establishing a "stray sand," the unexpected encountering of which at another well may result in a gas fire with attendant loss of life and property.

WASTE FROM SOME WELLS IN THE CUSHING FIELD.

A gas well that yields a large volume of gas was drilled in the Cushing field in January, 1913, on sec. 17, T. 17 N., R. 7 E. The well was cased as follows: Four hundred and twenty-one feet of 12½-inch casing, 546 feet of 10-inch casing, 1,030 feet of 8-inch casing, and 2,140 feet of 6⅝-inch casing.

The Layton sand, which was encountered at 1,420 feet, was "broken up" and gave no indication of oil or gas, but in the Jones sand, at 1,663 to 1,693 feet, a flow of gas estimated at 8,000,000 cubic feet a day was struck, which was allowed to escape while drilling was continued.

FIGURE 2.—Gas wasting from a well being drilled.

On January 26, 1913, the Wheeler sand was encountered at a depth of 2,140 feet, and a string of 6⅝-inch casing was inserted, shutting off the Jones gas from the bore hole, but still allowing it to waste into the air. In drilling the Wheeler sand the volume of gas wasted was increased by probably 40,000,000 cubic feet a day.

Drilling continued until February 5, 1913, when the tools became fast and in an attempt to dislodge them the drilling line broke on February 6. It was then decided to shut in the well, and seven days were lost in preparations. The well was shut in February 13, 1913, and the opening between the 8-inch casing and the 6⅝-inch casing was closed by a stuffing-box casing head, thus shutting in the Jones gas.

The owners began to utilize the Jones gas on February 16, selling a portion for drilling, pumping, and other purposes.

Owing to the faulty seating of the 8-inch casing it was not considered possible to shut the gas in entirely, and between 2,000,000 and 3,000,000 cubic feet were allowed to escape daily to avoid raising the pressure in the well to such a point that the gas would blow out under the 8-inch casing, the maximum back pressure carried being

270 pounds. The waste of gas from this well for the time that it remained uncontrolled probably exceeded 500,000,000 cubic feet.

April 10, 1913, a well was drilled into the Wheeler sand on sec. 4, Tp. 17 N., R. 7 E., and allowed to go "wild." The drillers left the well, and for four days there was no one at the property to care for it, the well wasting 37,000,000 cubic feet of gas daily through an 8-inch open hole. The roar of the escaping gas could be heard 2 miles away. This well was shut in April 17, after some 250,000,000 cubic feet of gas had been wasted.

FIGURE 3.—A burning gas well.

At about the same time, on sec. 20, Tp. 18 N., R. 7 E., gas was struck at about 520 feet in a 16-inch hole, and the well went "wild," 30,000,000 cubic feet of gas escaping daily for 50 days, the total waste being about 1,500,000,000 cubic feet. This well was shut in May 31, 1913.

Another well in sec. 8, Tp. 18 N., R. 7 E., was wasting probably more than 40,000,000 cubic feet daily. This well was shut in April 21, 1913.

Among the lesser wastes at that same time, a well in sec. 4, Tp. 17 N., R. 7 E., was wasting about 9,000,000 cubic feet daily and one in sec. 8, Tp. 17 N., R. 7 E., about 10,000,000 cubic feet daily.

All these five wells were simultaneously wasting gas while being drilled, and the total daily waste from them was about 126,000,000 cubic feet. They were all shut in later. In addition, a number of other wells were (in April, 1913) wasting 2,000,000 to 5,000,000 cubic feet daily during drilling operations and through improper casing.

The waste of gas at a burning gas well is shown in figure 3.

The wastefulness of existing methods of drilling and shutting in wells was generally admitted and regretted by the operators, but as there was no apparent remedy the waste was regarded as necessary and of no material importance. The following somewhat equivocal

article published in a journal[a] devoted to the petroleum industry excellently illustrates this attitude:

> While it is true that some big gas wells have been found at Cushing, in the defined oil district, it is also true that this gas has been found above the oil sand and that, when first found, it was impossible to drill through to the oil sand until the force of the gas had abated somewhat. It is also true that, while waiting for the pressure to subside, a lot of gas was wasted.
>
> However, as there is no market for the gas at Cushing, it might just as well be wasted. * * *
>
> * * * The gas belt of the Cushing field has been clearly defined. In this territory dry gas, which is of great commercial value, is found and there are a number of big wells in that part of the field. In no instance has a single Cushing operator, after getting a big gas well in the gas territory, allowed it to blow any longer than the interval in which he was getting it capped, and there is not a well to-day from which gas is being wasted wantonly.

Such enormous waste of an important natural resource indicates that the methods that were employed were faulty and that better methods, which shall at once be successful and practical, should be devised. For this purpose the Bureau of Mines proposed to investigate the possibilities of adapting the use of clay and water, which was devised for use with rotary rigs, and developed in Louisiana, Texas, and California, to the dry-hole method of drilling practiced in Oklahoma. To accomplish this it was necessary to obtain the cooperation of well operators that a practical test and demonstration of the method might be made.

DEMONSTRATIONS OF THE MUD-LADEN FLUID METHOD.

DEMONSTRATION AT THE GREIS WELL.

The first well for demonstration was offered by Mr. Henry N. Greis, of Tulsa, Okla. This well was in the S. ½ SE. ¼ sec. 8, Tp. 17 N., R. 7 E. It had been drilled to a depth of about 1,700 feet on April 11, 1913, when gas from the Jones sand was encountered unexpectedly. The gas was ignited from a forge on the derrick floor, and the fire destroyed the rig.

After the rig was rebuilt, drilling was continued until May 2, when it was stopped in black shale at a depth of 2,140 feet. The hole was then filled with mud-laden water, and was allowed to stand full of this fluid until May 5, when drilling was resumed. The Jones gas, which had been escaping from the well, was successfully excluded from the bore hole by the fluid mud and gave no further trouble.

The hole was found to be bridged at a depth of about 1,700 feet, where drilling had ceased because of the fire, the strata there having slaked from contact with clear water during the time required to rebuild the rig. In drilling out this bridge considerable difficulty was

[a] Fuel Oil Journal, May, 1913.

encountered from caving, but the drilling tools were on the bottom of the hole by May 7. The hole continued to cave at about 1,700 feet, and it was decided to insert 6⅝-inch casing. A special casing shoe 6 feet 4 inches long was made, and the casing was placed on May 9. Drilling was resumed May 10. The casing was lowered as the hole was drilled, and on May 11 it was securely seated at a depth of 2,147 feet, directly on top of the Wheeler sand.

On May 12 the hole was drilled 10 feet below the casing into the Wheeler sand. Bailing showed considerable gas, but the well was quiet and no gas escaped. The bailer and tools brought out thick mud and drilling became slower. May 14 a small quantity of sandstone was thrown into the well by the drilling contractor and drilled up, the tools going to the bottom of the hole and the bailer following to within 1 foot of the bottom, where it stuck. The sand line was parted in an effort to pull the bailer loose.

On May 15 the bailer was grabbed by a "latch jack," but the latch was jarred through the bail. On May 16 a bell socket was used, which brought up pieces of the bailer. At no time was any difficulty experienced in getting a hold. On May 19 the bell socket stripped off the mandrel and work stopped for a new fishing tool. The bell socket was recovered May 20 by means of a tubing spear. On May 21 drilling was resumed in an attempt to drill out the remainder of the bailer, about one-half having been removed by the bell socket. On May 22 the sand pump that had been used for removing the pieces of the bailer as they were drilled up became fast in the hole and could not be loosened. The fluid was bailed out of the hole, and by means of a latch jack a hold obtained on the sand pump, which was easily removed on May 26.

The gas pressure cleansed the well of mud and the tools were started in to drill up the bailer in the dry hole. Large pieces of steel were blown from the well by the gas, the flow of which increased gradually as the hole was deepened, until the tools would no longer drop with force enough to make hole. On May 28 the well was shut down and the flow of gas measured. The flow was more than 22,000,000 cubic feet a day.

On May 31 the well was filled with mud-laden fluid. A gate valve was placed on top of the 6⅝-inch casing and connected by means of a swage nipple to a double joint of 10-inch casing provided with a top gate valve. The casing was anchored to "dead men" buried below the derrick floor and was securely braced in the derrick to avoid danger of its swinging so as to loosen the joints at the top of the well. The lower gate valve and the method of anchoring the casing are shown in figure 4.

In filling the well with fluid the lower gate valve was closed, the upper one opened, and the chamber between the valves was filled

with the fluid; the upper valve was then closed and the lower valve opened. The pressure in the filling chamber being equalized, the mud-laden fluid, owing to its weight, fell to the bottom of the well, being replaced in the filling chamber by an equal volume of gas. By again closing the bottom valve and opening the top valve, the gas displaced by the fluid was released and the chamber was ready for a new charge. This operation was repeated until the column of fluid in the well was so high that its hydrostatic pressure exceeded the rock pressure of the gas. The rest of the well was then filled by pumping the fluid directly in.

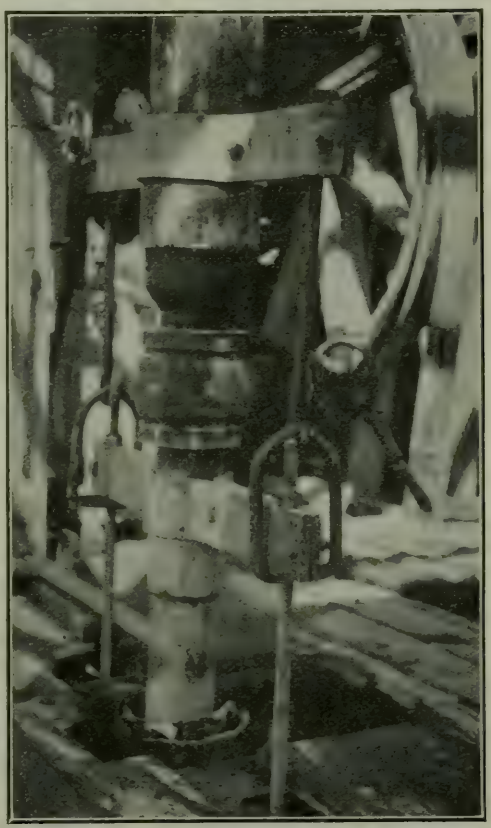

FIGURE 4.—Well with filling chamber attached, showing lower gate valve and part of filling chamber.

Drilling was resumed June 2 and a quantity of steel was removed from the well, some pieces exceeding 1 pound in weight. The tools dropped freely and broke up chunks of steel that were not broken by the tools when working in the dry hole with gas escaping.

On June 6 the drilling contractor again threw a small quantity of soft sandstone into the well and the bailer stuck on the first run after the stone had been put in. All efforts to pull the bailer out by the sand line failed and the sand line broke. The fluid was bailed out of the hole and the bailer recovered on June 8 by means of a latch jack. When the bailer was loosened it was thrown to the top of the derrick by the gas that was liberated by the removal of the fluid. The well was then filled again with the fluid and drilling continued until June 12, when the derrick was rigged for casing. All 10-inch and 12½-inch casing were pulled on June 13, the surface casing and the 8-inch and the 6⅝-inch casing being left in.

On June 14, 2,177 feet of $5\frac{3}{16}$-inch casing with a lead shoe on the bottom was seated in the well and the mud-laden fluid bailed out. The lead shoe and casing proved tight against the pressure of the column of fluid on the outside, which stood to the top of the $6\frac{5}{8}$-inch casing.

Drilling was resumed and 22 feet of hole was made in advance of the casing. This hole struck a second gas sand, and the well was shut in and again filled with the fluid on June 17. The $5\frac{3}{16}$-inch casing was withdrawn on June 18. The hole was then reamed from 2,177 to 2,198 feet and the $5\frac{3}{16}$-inch casing was reset June 20 with a $5\frac{3}{16}$-inch by $6\frac{5}{8}$-inch conical sleeve packer, carrying 26 inches of rubber on the bottom. The fluid was bailed out and the casing found to be tight, the well was quiet, and no gas was escaping.

Drilling was resumed June 21. Oil was encountered the next day, and on June 23 was spraying into a tank with a fine showing for a large production. During the first 24 hours after the oil started to flow into the tank the gaged flow was 60 barrels, and on June 25 drilling was discontinued.

RESULTS OBTAINED BY THE TEST.

This demonstration of the well-drilling method proposed by the Bureau of Mines proved the following points:

1. The escape of gas from a well during drilling can be controlled, and formations can be sealed so as to prevent the further escape and waste of gas.

2. The sealed formations may be reopened at any time by removing the fluid from the well, the pressure of the gas cleansing out the mud so that the yield will not be affected.

3. By sealing off gas with mud-laden fluid it is possible to drill entirely through a gas-bearing sand without wasting gas.

4. A record of the gas-bearing formations can be obtained with an accuracy that is impossible with the "dry hole" method of drilling, for the reason that on drilling a hole "dry" the gas blows all the finer drill cuttings from the well and only occasionally are fragments found that are large enough to show the character of the formation penetrated.

The following record indicates the character of the formations penetrated during the demonstration, the terms "sand" and "lime" are those recorded by the driller, the samples not having been examined by a geologist:

Record of well from top of Wheeler sand to oil sand.

Depth.	Material.		Estimated volume per day of gas flow.
	Thickness.	Kind.	
Feet.	*Feet.*		*Cubic feet.*
2,140 to 2,147	7	Black shale	
2,147 to 2,173	26	Blue-gray lime (gas)	22,000,000
2,173 to 2,179	6	Gray sand	
2,179 to 2,181	2	Brown sand	
2,181 to 2,186	5	Blue shale	
2,186 to 2,191	5	Black shale	
2,191 to 2,199	8	Gray lime (gas)	5,000,000
2,199 to 2,213	14	Gray sand (gas)	300,000
2,213 to 2,225	12	Gray sand (oil)	

The time spent in the different operations at this well was as follows:

Time spent in drilling well.

May 2, 1913, started demonstration.
June 25, 1913, completed demonstration, with well producing oil.

	Days.
Drilling, 8 days with double tours, 11 days with single tours	19
Fishing and shutdowns	17
Drilling on lost bailer and removing bits of steel	8
Casing	5
Rigging up and filling well with mud-laden fluid	5
Total elapsed time	54

DEMONSTRATION AT THE SINCLAIR, WHITE & UFER WELL.

Sinclair, White & Ufer offered the next well to be treated as a demonstration. The problem was similar to that encountered in drilling the Greis well, in that the well had been already drilled to the top of the Wheeler sand and the Jones sand was exposed. The gas from the Jones sand had a larger volume and higher pressure than in the Greis well. The purpose of the experiment was to drill through the Wheeler sand without allowing waste of gas or waiting for the gas pressure to diminish. This well was on sec. 8, Tp. 17 N., R. 18 E., and about one-quarter of a mile east and one-quarter of a mile north of the Greis well.

Preparations were commenced on May 21, when a pit for holding the mud-laden fluid was started.

On May 29, when the well had been drilled into the top of the Wheeler sand, an attempt was made to fill the well with fluid pumped directly into the hole, but the fluid was blown out by the gas, and it became necessary to trap the fluid into the well by the method employed at the Greis well. The well was filled and drilling resumed May 31. After drilling about 21 feet the tools became fast on the following day and could not be recovered until the fluid had been bailed out and the gas allowed to clean the hole around the tools,

after which the well was again filled with fluid and the tools recovered June 10.

Drilling was resumed June 11 and continued to June 13, when the well was cased with $5\frac{3}{16}$-inch casing. Drilling was resumed June 14. On June 15 the fluid was bailed from the inside of the $5\frac{3}{16}$-inch casing, and the shoe was found to be leaking. After many attempts to pull this casing, it was again tested for tightness on June 21, and, being found tight, drilling was resumed. The well was finished with the hole full of fluid and was shut in for a gas well.

While these two demonstrations were being given, the method was used at other wells in the Cushing field, and now, through the efforts of the bureau, the method is familiar to the drillers in this field, and may be employed in drilling through gas sands.

DEMONSTRATIONS AT OTHER WELLS.

Among the first to take up the new method was the Devonian Oil Co., who applied it to well No. 12, on sec. 8, Tp. 17, R. 7 E. The work was done entirely by themselves, under the instructions of the writers.

This well had been drilled to the top of the Wheeler sand, which contained a large volume of gas. The well had been shut down with 400 feet of open hole below the bottom of the casing, and the open part had caved for 180 feet from the bottom. The work of filling the well with fluid was started June 8, 1913, 40 feet of $6\frac{5}{8}$-inch casing being used for a filling chamber. The well was allowed to stand full of fluid June 9, and drilling was resumed June 10. On June 12 the hole had been entirely cleaned out and a new hole had been drilled through the first pay of the Wheeler sand into a bed of shale that separates the first and second pays of that sand. On June 13 the well had been cased through the first pay, which gives a strong flow of gas.

The actual time required to clean out 180 feet of cavings and drill through 28 feet of hard limestone, containing a large volume of gas having a rock pressure of 600 pounds per square inch, was 36 hours.

April 16, 1913, at the request of the McMan Oil Co., a representative of the bureau visited the company's well No. 1, on sec. 8, Tp. 18 N., R. 7 E., and gave instructions for shutting it in. The well was successfuliy shut in, in accordance with these instructions, on April 21.

This well had a measured flow of 40,850,000 cubic feet of gas in 24 hours, the rock pressure being 195 pounds to the square inch. The gas was struck at a depth of 665 feet. The first 540 feet of hole was cased with $12\frac{1}{2}$-inch casing. A string of 10-inch casing, with the lower end wrapped with burlap to fill the hole and prevent escape of gas or loss of cement, was inserted to a depth of 620 feet. The space around the casing was filled with grout for 90 feet from the

bottom, 10 sacks of cement mixed with equal parts of sand being used. This 10-inch casing was placed to shut out water in a bed above the gas sand. After the cement had set the space between the 10-inch and 12½-inch casings was filled with clear water to hold the cement and in order to test for tightness. The casing proving tight the well was shut in as a gas well for local fuel supply.

At the request of the Barnsdall Oil Co. instructions were given for deepening their well No. 13 in lot No. 298, on the Osage Reservation.

This well was drilled in April, 1912, and proved one of the largest producers of gas in that section, having a natural flow of 40,000,000 cubic feet a day. It was utilized during the winter of 1912–13 to supply gas commercially. In cleaning the gas for pipe-line delivery, separators were used, from which a considerable quantity of petroleum was collected.

An attempt had been made to deepen the well in search for oil, which was assumed to underly the gas, but, owing to the great volume and pressure of the gas, this attempt had proved unsuccessful and had been abandoned.

July 23 the well was filled with mud-laden fluid and the gas sealed off by the method that had been employed at the Greis well. Preparations were at once made for drilling, the hole was reamed down, and $5\frac{3}{16}$-inch casing set on the bottom. The fluid was bailed out and drilling resumed, the gas being shut in by a stuffing-box casing-head between the $6\frac{5}{8}$-inch and $5\frac{3}{16}$-inch casings. When the well had been drilled 57 feet deeper, a second gas sand was encountered and the well was shut in to retain the gas.

The work was performed under the direction of the superintendent, W. G. Boggs.

PRECAUTIONS TO PREVENT STICKING OF TOOLS.

Soft sandstone was put in the Greis well by the contractor in each instance immediately before the bailer stuck. The purpose of the contractor in putting this sandstone in the well was to facilitate drilling, but the result was to thicken the mud. When the bailer was run to the bottom of the hole it displaced thick mud and sand which settled around the sides of the bailer and packed, thus putting the full pressure of the column of fluid on the bailer in addition to the friction hold of the mud. Liberating the gas by removing the mud-laden fluid relieved this pressure and cleaned the hole, so that the bailer could easily be recovered.

A similar occurrence was noted in the Sinclair, White & Ufer well, where the sticking of the tools was due to the limestone drillings settling back after the tools had been in the hole for five hours continuously.

These experiences point to the necessity of keeping the hole clean and not drilling too much hole in sandstone or limestone without cleaning. The drillings are displaced more in a wet hole than in a dry hole and the driller must allow for this by reducing the length of time and the amount of drilling between the periods of bailing.

USING CLEAR WATER IN PLACE OF MUD-LADEN FLUID.

Mud-laden fluid must be used with judgment and clear water must not be used in place of the fluid if good results are to be expected. At a well in the Cushing field the superintendent decided that clear water would serve as well as the fluid and tried clear water.

The well had been cased to a depth of 1,690 feet with 8-inch casing and was drilled 8 feet into the Wheeler sand May 21, 1913, when the volume of gas liberated became so great that further progress was impossible. The well was allowed to remain open three days when the volume of gas being wasted was found to be 20,140,000 cubic feet a day. The well was then shut in and arrangements were made for continuing the drilling. The gas pressure had fallen considerably and it was possible to drill 5 feet farther, or 13 feet in all, into the Wheeler sand.

On June 2 the owners attempted to exclude the gas from the well by filling it with clear water, using the method described for filling a well with mud-laden fluid. The clear water disappeared into the surrounding beds and caused the walls of the well where not protected by casing to slake and cave into the hole; furthermore, as the water flowed out of the hole as rapidly as it was put in, a column having sufficient head to overcome the gas pressure could not be obtained.

After these efforts proved futile the well was allowed to remain open and waste gas for several days. The owners being unable to complete the well, appealed to representatives of the Bureau of Mines, and, under their instructions, muddy fluid was introduced into the well and the gas "killed" on June 10, after which drilling was resumed.

The well had caved so badly in the meantime that it was difficult to keep the hole clean and on July 11 a string of 6⅝-inch casing was put in, but owing to the caving it was two weeks before the casing was seated. The well was shut in as a gas well.

The difficulties encountered were largely the direct result of introducing clear water into the well and starting a cave that was very difficult to overcome.

In drilling a well on sec. 8, T. 17 N., R. 7 E., water from an upper bed broke in after gas had been struck. The gas forced the water from the well with such violence that it was thrown over the top of the

derrick. Drilling was suspended until the gas could be "killed" and the water excluded from the hole by the mud-laden fluid method. The work was done under the supervision of the superintendent of the property and proved very successful. The well was completed as an oil well.

FILLING A WELL BY THE TUBING METHOD.

A well that presented some unusual difficulties was drilled in August, 1913, near Haskell, Okla., in sec. 18, T. 15 N., R. 15 E.

This well had been drilled to a depth of about 950 feet and was cased with 12½-inch casing to a depth of 320 feet. At about 900 feet a gas sand was encountered that yielded a flow of about 40,000,000 cubic feet a day. At 950 feet a bed containing sulphur-bearing salt water was encountered; the water was thrown over the top of the derrick by the gas, and the flow was about 5,000 barrels a day.

An attempt was made to case the well through the gas and water bearing strata with 10-inch casing, but after being lowered to a depth of 520 feet the casing became "frozen" in a large cave and could not be moved. At this point the Bureau of Mines was asked to render assistance and a representative of the bureau took charge of the work of getting the well under control.

It was found impossible to shut the well entirely in, because the surface casing in the well was too short to withstand the pressure of the gas, consequently it became necessary to resort to the tubing method of inserting the mud-laden fluid, the only water available for mixing the fluid being the salt, sulphur-bearing water that was being ejected from the well.

A stuffing-box casing-head was placed on the 12½-inch casing and clamped to the 10-inch casing, and a tee casing-head was placed on the 10-inch casing. Then 3-inch tubing was lowered through the top opening of the tee to a point a short distance from the bottom of the well and below the gas sand. The space between the tubing and the casing top was packed tightly enough to withstand the pressure of the gas in the well, and a valve was connected to the side opening in the tee.

Mud-laden fluid was pumped into the well through the 3-inch tubing and the gas and salt water displaced by the fluid were allowed to escape through the valve on the side outlet of the tee. By means of this valve the amount of gas and salt water permitted to escape was regulated and the escape of the mud fluid prevented. As the fluid rose within the well it tightly sealed the water and gas strata and finally filled the well.

The time required to bring the well under complete control from the starting of the fluid into the well was 30 minutes. Drilling was resumed, and 8-inch casing was seated at a depth of about 1,000

feet. The mud fluid was then bailed from the inside of the casing and drilling continued to completion without further mishap.

The tubing method described above was also used in September, 1913, at a well in the Cushing field on sec. 34, Tp. 18 N., R. 7 E. The condition of this well when the mud-laden fluid method was applied was as follows:

The 6⅝-inch casing had been frozen at about 1,900 feet and drilling had been continued to the Wheeler formation at about 2,100 feet, where gas was struck that showed a pressure of 600 pounds to the square inch. The volume was not recorded. In trying to loosen the 6⅝-inch casing with nitroglycerin a premature explosion took place at about 820 feet below the surface, shattering the 6⅝-inch casing and also the 8-inch casing, all other casing having been recovered. When the casings were shattered by this shot, water entered the well from the upper beds and was blown out over the top of the derrick by the gas.

An attempt was made to shut this well in, but as the casing was shattered close to the surface, the gas and water came up outside of the casing, making it impossible to shut off the flow by closing the top; consequently, the tubing method of inserting the mud-laden fluid was used. In 20 minutes from the time that the fluid was started into the well, the well was entirely under control. The fluid not only sealed off the gas, but passed through the hole that had been shot in the casing, penetrated the water bed, and sealed off the water. Drilling was resumed in this well as soon as the tubing through which the fluid had been introduced was removed.

A somewhat different condition was encountered in August, 1913, in a well near Morris, Okla. This well was drilled through a producing oil sand at 1,600 feet directly beneath which a water-bearing bed was encountered. There is a shell or hard stratum between the oil and water-bearing strata, but it is too thin to set a packer in and thus exclude water from the oil sand.

The well was filled with mud-laden fluid, which sealed each stratum separately, and casing was set through the fluid. Then the fluid was bailed from the inside of the casing and the well drilled into a lower oil sand.

By the use of this method a deep well may be drilled to a lower sand and a shallow well drilled to an upper sand (fig. 5), the oil being taken from the two sands without allowing water to enter either and without loss of oil or gas.

DRILLING A "COMBINATION" WELL.

In September, 1913, the method was successfully used at a well in the Wicey pool near Bixby, Okla. This well had been drilled to a gas sand at about 1,700 feet and 6⅝-inch casing had been set. The gas

had a rock pressure of 810 pounds per square inch and an estimated volume of more than 40,000,000 cubic feet a day. Owing to the great volume and pressure of the gas, the drilling tools could not be lowered into the well, and the Bureau of Mines was asked to render assistance.

On September 5, 1913, under the supervision of a representative of the bureau, a gate valve was placed on the top of the $6\frac{5}{8}$-inch casing, a double joint of 8-inch casing was set up in the derrick on top of the gate valve, and a second gate valve was placed on top of the double joint of casing. Mud fluid was then introduced into the well through the 8-inch chamber.

On September 6 the well was under control, and drilling was resumed. On September 7 the hole was through the gas sand.

The next day a string of $5\frac{3}{16}$-inch casing fitted with a packer at the lower end was inserted into the well, and on September 9 the fluid was bailed from the well and the gas allowed to clean out the hole. The casing was then seated, thus excluding the gas from the inside of the casing, and drilling was resumed. A stuffing-box casing head or bradenhead was placed on the top of the $6\frac{5}{8}$-inch casing and was packed around the $5\frac{3}{16}$-inch casing to control the gas.

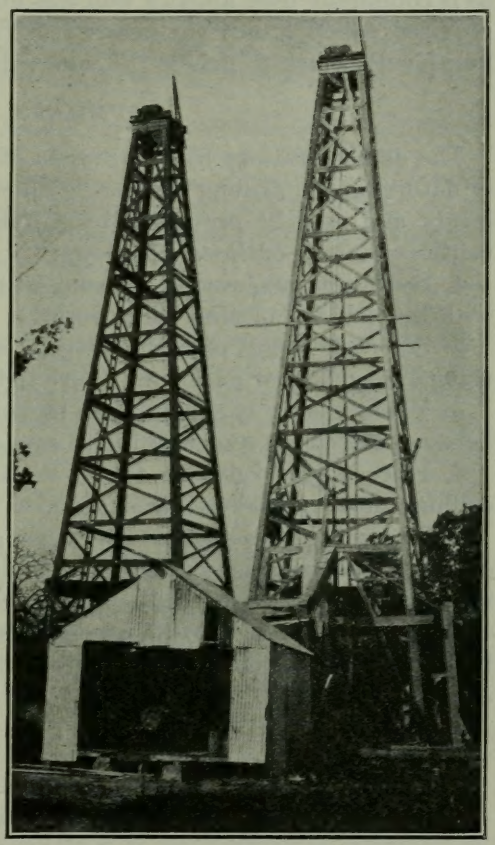

FIGURE 5.—Two adjoining wells that produce from different sands.

The well was finished by drilling into a lower oil sand and bringing the oil up inside of the $5\frac{3}{16}$-inch casing while the gas was recovered between the casings, making a combination well in which the oil and gas were kept separate and waste was prevented.

By setting the $6\frac{5}{8}$-inch casing on top of and the $5\frac{3}{16}$-inch casing with a packer immediately below the gas sand, the gas was conducted to the surface without coming in contact with the walls of

the hole, so that any possible loss from the escape of gas into other beds was prevented.

Eight-inch casing was used in making the filling chamber, as this was the only size casing available, and the work could be finished in less time than would have been required to obtain two joints of 10-inch casing. In all the work done by the representatives of the Bureau of Mines on various gas and oil wells, standard material such as is commonly used about a well was utilized. The only equipment required which is not commonly used about a drilling well was a pump with which to handle the mud-laden fluid.

SUMMARY.

The demonstrations by the Bureau of Mines show that the waste of natural gas in drilling and casing oil or gas wells is entirely unnecessary and may be prevented by suitable precautions. These precautions may be outlined as follows:

1. Seal each gas-bearing stratum as it is encountered by drilling with the hole full of mud-laden fluid.
2. Set each string of casing with a secure and water-tight seat, using a long shoe or packer to assure tightness.
3. When casing through a gas-bearing stratum, keep the space between the casing and wall full of muddy fluid.
4. Place a gate valve on top of the inner string of casing before drilling into any gas-bearing stratum.
5. The string of casing through which gas is taken should be seated on top of the gas sand and the gas should be prevented from coming in contact with the wall of the hole above the sand.

This precaution should be observed when gas is taken through a bradenhead at an oil well as well as when a well is drilled for gas alone.

PUBLICATIONS ON PETROLEUM TECHNOLOGY.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls., 10 figs.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 10. Liquefied products from natural gas; their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

TECHNICAL PAPER 25. Methods for the determination of water in petroleum and its products, by I. C. Allen and W. A. Jacobs. 1912. 13 pp., 2 figs.

TECHNICAL PAPER 26. Methods of determining the sulphur contents of fuels, especially petroleum products, by I. C. Allen and I. W. Robertson. 1912. 13 pp., 1 fig.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells as practiced in California, by Ralph Arnold and V. R. Garfias. 1913. 12 pp., 1 fig.

TECHNICAL PAPER 36. The preparation of specifications for petroleum products, by I. C. Allen. 1913. 12 pp.

TECHNICAL PAPER 37. Heavy oil as fuel for internal-combustion engines, by I. C. Allen. 1913. 36 pp.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas, and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 42. The prevention of waste of oil and gas from flowing wells in California, with a discussion of special methods used by J. A. Pollard, by Ralph Arnold and V. R. Garfias. 1913. 15 pp., 2 pls., 4 figs.

TECHNICAL PAPER 49. The flash point of oils; methods and apparatus for its determination, by I. C. Allen and A. S. Crossfield. 1913. 31 pp., 2 figs.

TECHNICAL PAPER 51. Possible causes of the decline of oil wells and suggested methods of prolonging yield, by L. G. Huntley. 1913. 32 pp., 9 figs.

TECHNICAL PAPER 53. Proposed regulations for the drilling of gas and oil wells, with comments thereon, by O. P. Hood and A. G. Heggem. 1913. 28 pp., 2 figs.

TECHNICAL PAPER 57. A preliminary report on the utilization of petroleum and natural gas in Wyoming, by W. R. Calvert, with a discussion of the suitability of natural gas for making gasoline, by G. A. Burrell. 1913. 23 pp.

TECHNICAL PAPER 66. Mud-laden fluid applied to well-drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

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